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Agency

Office of Research and
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Washington, DC 20460

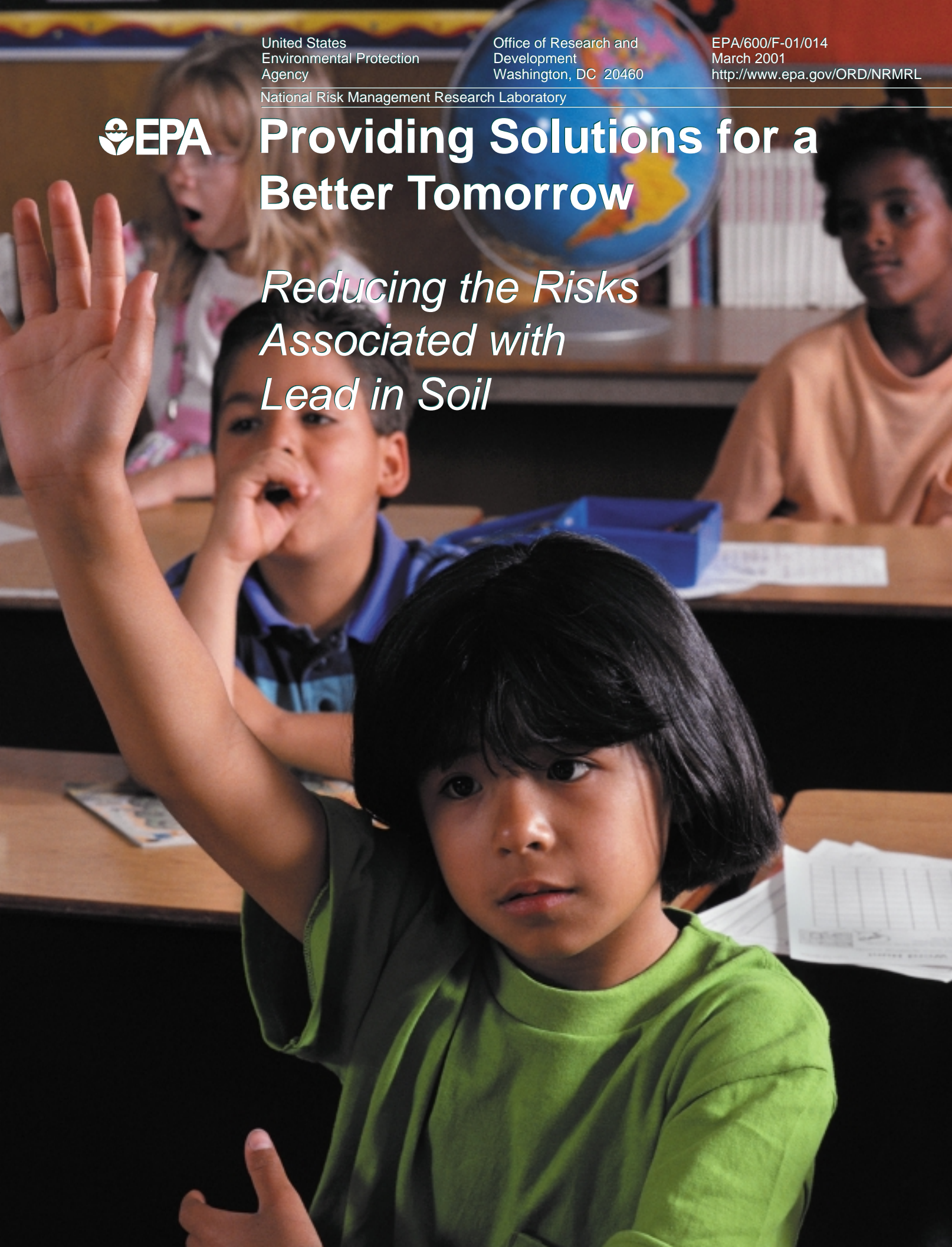
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National Risk Management Research Laboratory



Providing Solutions for a Better Tomorrow

*Reducing the Risks
Associated with
Lead in Soil*



NOTE

Although this brochure contains widely-applicable information about the risks of lead exposure, the hydroxyapatite treatment technique described within is primarily aimed at remediation of Superfund sites; the use of the patented hydroxyapatite technique does not satisfy the goals of residential soil remediation under the Toxic Substances Control Act. This brochure has been peer and administratively reviewed and approved for publication as an EPA document.



US EPA Office of Research and Development

“Nearly 1 million children living in the United States have lead levels in their blood that are high enough to cause irreversible damage to their health.”

Centers for Disease Control and Prevention, 1998

Introduction

Flaking paint, decades of leaded gasoline use, mining operations, smelter and industrial emissions, waste incineration, and application of insecticides and fertilizers have all contributed to elevated lead levels in soils. Urban environments, with their higher concentrations of industries, aging buildings, and vehicular traffic, have correspondingly higher levels of lead in soil. To complicate matters, lead seems to remain near the surface of the soil where it is deposited — increasing the chance of exposure.

The quote highlighted at the top of this page brings the risks associated with lead exposure into perspective. The U.S. Environmental Protection Agency (EPA) has acknowledged these significant risks and the need for a better understanding of the associated issues. EPA's Office of Research and Development, in cooperation with other scientists and engineers, has developed risk assessment tools that estimate the risks associated with lead exposure and a cost-effective management technique to reduce the risks associated specifically with exposure to lead in soil. The following information is presented to better inform citizens, decisionmakers, and remediation engineers of these risks and give them some tools to help solve the problem.

Effects Associated with Exposure to Lead

Whether lead enters the body through ingestion or inhalation, the biological effects are the same: normal cell function and a number of physiological processes can be disrupted. In humans, lead primarily affects the nervous system, blood cells, and processes for the metabolism of

vitamin D and calcium. Lead can cause reproductive toxicity (i.e., it can be transferred easily to the developing fetus via the placenta), impaired tooth and bone development, kidney damage, and anemia. Other adverse effects which may result from elevated blood lead levels include: lower IQ scores; poor attention levels; hearing, speech and language problems; reading disabilities; reduced motor skills; and poor hand-eye coordination.

Although no safe lower threshold level for these effects has been established, available evidence suggests that lead toxicity may occur at levels as low as 10-15 micrograms of lead per deciliter of blood ($\mu\text{g}/\text{dL}$). The current level of concern established by the Centers for Disease Control and Prevention (CDC) and the American Academy of Pediatrics is 10 $\mu\text{g}/\text{dL}$. According to recent CDC estimates, 890,000 U.S. children under age 6 (i.e., 72 months) have elevated blood lead levels. In light of these statistics, lead poisoning is expected to cost billions of dollars in medical and special education expenses and decreased future earnings.

Why Children are at Greater Risk

Compared to adults, children proportionately eat more food, drink more fluids, breathe more air, and play outside more. Natural curiosity and the tendency to explore leaves children open to health risks that adults can more easily avoid. In crawling on the ground and playing with and in soil, ingestion of contaminated soil and dust (by chance and on purpose) can occur more often (Fig. 1).

Children's bodies are not yet fully developed, so exposure to contaminants may affect their growth and development. Children may be more or less sensitive than

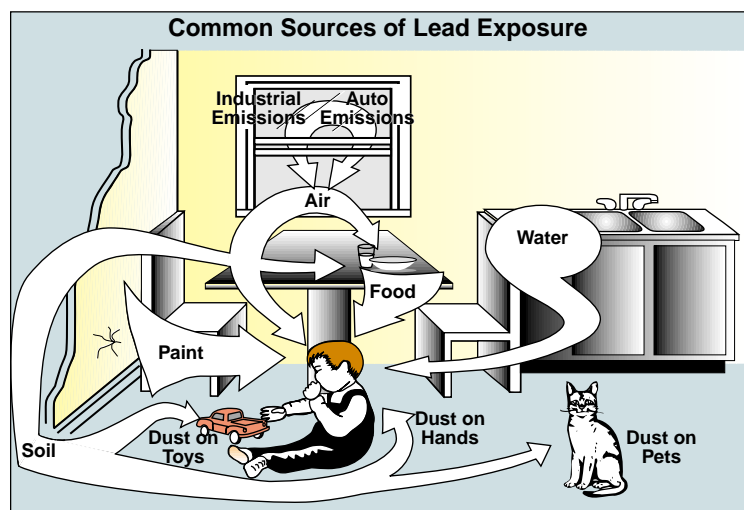


Figure 1. Some of the sources of lead exposure are shown at left. Since children are more often in direct contact with potentially-contaminated soils, they face greater risk of exposure to soil-related contaminants. Children younger than 6 years are most at risk for exposure to lead in soil.

adults when confronted with an equivalent level of exposure to pollutants. These age-related variations in susceptibility are due to many factors, including body composition, metabolism, state of the immune system, and differences in the way the body absorbs, distributes, transforms, and excretes a contaminant.

With exposure to lead, children absorb into their blood and retain more of the contaminant in proportion to their weight than adults. Nutritional deficiencies such as inadequate iron and calcium may increase the chances for lead absorption. Depending on a child's stage of development at time of exposure, lead-damaged cells can hinder development of important body systems.

Bioavailability and Its Importance

The risk associated with a contaminant depends on how easily an individual absorbs it; this measure of absorption by the body defines contaminant "bioavailability." Another important factor is how easily the contaminant is delivered to the part of a body (e.g., brain) where its toxic action can occur.

Should a heavy metal like lead be bound to other molecules when ingested, it might pass through the body without being absorbed into the blood. While absorbed lead has toxic effects, not all soil lead is bioavailable. Three factors contributing to varying bioavailability are: the size of the lead-containing particle (i.e., perhaps the particles are too large to be dissolved and/or absorbed); the chemical form of lead in the soil; and the geochemical matrix incorporating that form of lead (i.e., lead may be entrapped in a less soluble compound).

Contaminant bioavailability is important when considering remediation needs. Historically, remediation decisions have been based on an assumed bioavailability level (30% is the accepted default level) for all forms of lead in soil. Using the integrated exposure uptake biokinetic (IEUBK) model developed by EPA's National Center for Environmental Assessment, blood lead levels can be predicted for a population given the amount of soil ingested and its bioavailability.

Figure 2 demonstrates how the bioavailability of lead in soil affects estimates of lead concentration in the body. Using EPA's IEUBK model, if the lead bioavailability is decreased (e.g., through soil treatment techniques), higher exposures would result in the same blood-lead effect as exposure to lead species with greater bioavailability. Such a finding could translate into significant savings in cleanup costs.

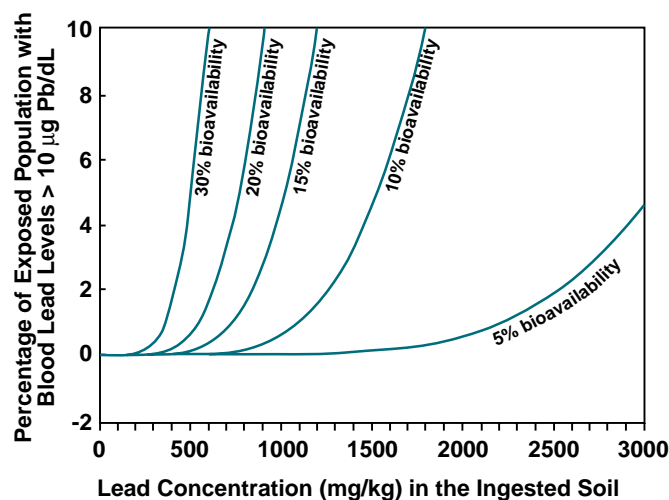
Determining Bioavailability

Even with the IEUBK model, direct bioavailability estimates are not easily obtained. Clearly, children cannot be used as test subjects to determine the amount of lead absorbed through exposure to local soils; surrogate measures must be used that best estimate lead uptake. EPA Region VIII scientists have used immature swine to examine oral lead bioavailability. They have completed test studies using swine dosed with soils containing varying levels and species of lead. Soil lead bioavailability ranged from 6% to 86% relative to freely soluble (aqueous) lead acetate.

Scientists from EPA's Region VIII have been focusing on the use of site-specific risk-based information in determining the level of cleanup needed. For instance, by first determining that the bioavailability of lead contaminants in soil at a Bingham Creek, Utah, site was lower than the default level (19% instead of 30%), less cleanup was necessary to manage the risk at the site. With less disruption of the site, an estimated \$4 million was saved through this refinement of evaluation techniques.

Building on Region VIII's *in vivo* (live animal model) studies, an *in vitro* (artificial, non-animal) chemical extraction approach has been devised to imitate the physiology of human and animal digestive tracts. Results from this chemical method, using the same soil samples, have compared well with the results of the swine study. Such good correlation may make further animal bioavailability testing unnecessary. A Solubility-Bioavailability Research Consortium is currently verifying and standardizing this *in vitro* approach.

Figure 2. Information on the bioavailability of lead in soil at a specific site provides a more accurate representation of the risk at that site. The chart at right (based on EPA's IEUBK model) shows that if a treatment method reduces the bioavailability of lead in soil (e.g., from the 30% assumed value to 5%), the risk from exposure can be reduced and less remediation may be needed. This can result in lower cleanup costs and less disruption of the environment.



Reducing the Risks Associated with Lead Contaminants in Soil

In 1992, the Remediation Technologies Development Forum (RTDF) was organized by EPA to foster collaboration between the public and private sectors in developing innovative solutions to mutual problems of contaminated materials. EPA's National Risk Management Research Laboratory (NRMRL) and the DuPont Corporation formed the "In-place Inactivation & Natural Ecological Restoration Technologies" (IINERT) Soil-Metals Action Team in November 1995, under the RTDF. The 'IINERT' Soil-Metals Action Team includes representatives from industry and government who share a common interest in developing and validating surrogate measures of bioavailability. Through this effort, the Team supports the Solubility-Bioavailability Research Consortium mentioned earlier.

The IINERT team also has as objectives developing and validating *in situ* (in-place) techniques as viable technologies for eliminating the hazards of metals in soils and surface materials. Their purpose is to develop and demonstrate in-place inactivation and natural ecological restoration technologies that reduce or eliminate the human health and ecological risks of heavy metals in soil and to achieve regulatory and public acceptance of these technologies.

The 'IINERT' Soil-Metals Action Team concluded that if soil-lead species can be converted to less bioavailable forms, the overall lead risk of the soil can be reduced. Therefore, three facets of the issue are being studied: 1) innovative approaches to reduce lead bioavailability; 2) techniques to measure the conversion of lead to less bioavailable forms; and 3) identification and quantification of soil lead forms in intact soil systems and their relationship to bioavailability.

Developing Innovative Alternative Remediation Methods

Efficient remediation treatments for soils attempt to capitalize on the differences in physical and chemical properties between a contaminant and soil constituents. For example, remediation efforts for metal-contaminated sites use properties such as solubility, density, particle size distribution, surface chemistry, boiling point or magnetic susceptibility to allow separation and recovery.

Metals found as relatively soluble species or weakly bound to other soil components might be dissolved by applying mild acids. If the metals are present as separate mineral particulates, their typically higher density might permit the physical separation of these species from the less dense soil constituents. If the metal species are volatile, then a soil heating method might allow recovery. Separation methods relying on the magnetic susceptibility of ferromagnetic or strongly paramagnetic metal species have also been attempted. If separation techniques are not feasible, the metals can be bound in a solid cement or vitreous (glass) matrix.

Soil-lead remediation has typically been accomplished by soil removal for off-site disposal, covering, or diluting by mixing with uncontaminated soil. Cost (approximately \$1.6 million per acre foot), logistical concerns, and regulatory requirements associated with excavation, *ex situ* (off-site) treatment and disposal can make *in situ* treatment an attractive option. Current understanding of lead exposure, associated bioavailability factors, and environmental chemistry may allow development of less costly and environmentally less disruptive methods of remediation.

Innovative Approach

NRMRL, as part of its effort within IINERT, has demonstrated that by adding phosphorus (P) to lead-contaminated soil, lead can rapidly and effectively be bound into a stable compound called pyromorphite (see Fig. 3) that will rarely be absorbed if ingested. Also, *hydroxyapatite* has proven to be an effective source of phosphorus for binding with and reducing bioavailable lead in contaminated soil to below the U.S. EPA action level of 15 micrograms of dissolved lead per liter of drinking water.

NRMRL scientists have demonstrated that hydroxyapatite effectively immobilizes lead in soil even in the presence of interfering elements and compounds (e.g., anions, cations, and metals such as zinc, cadmium, nickel, copper, iron, and aluminum). The completeness and rate of this transformation have been found to depend upon the lead species, amount of hydroxyapatite added, and the pH (acidity/alkalinity) of the soil system. The speed at which soluble lead and phosphorus from hydroxyapatite react to become pyromorphite illustrates that the reaction can potentially occur during transit through the gastrointestinal tract — further reducing the potential exposure to bioavailable lead.

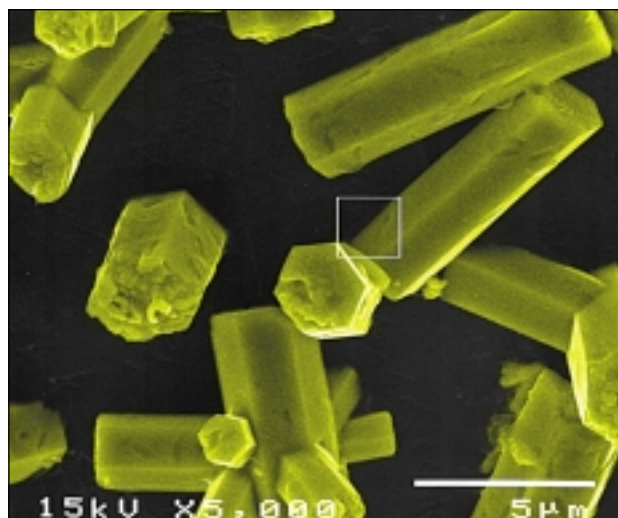


Figure 3. Pyromorphite crystals. Phosphorus from a hydroxyapatite additive can immobilize soil-based lead into this stable compound and make it less bioavailable.

The hydroxyapatite *in situ* inactivation technique (for which EPA was awarded a patent) has captured the interest of industry and the remediation research community. As tested in field studies by EPA's Region VII, the cost for this innovative, less disruptive method is in the thousands of dollars per acre foot of treated soil (in contrast to traditional treatment costs of more than a million dollars per acre foot). The technique, employing common agricultural application and tilling approaches for the addition of hydroxyapatite, leaves the treated soil capable of sustaining plant growth, which can in turn hold the soil in place and act as a barrier against contact with soil contaminants.

Conclusion

Efforts to reduce exposure to lead contamination have been very effective in the last two decades. EPA's ban on lead in gasoline and the Consumer Product Safety Commission's ban on lead in paint have reduced potential exposure considerably. Since lead solder is no longer used in the canning of foods, another avenue of exposure has been closed. Declining reliance on lead solder and lead pipes for the distribution of drinking water has further reduced exposure potential.

Some simple remedies can reduce the risk of exposure to lead in soil and dust. Careful handwashing should become a practice after contact with soil and before eating. Toys, bottles, and pacifiers should be cleaned — especially after use outside. Floors, window sills, and other surfaces should be cleaned regularly to reduce the risk of exposure to lead-contaminated dust. Deliberate ingestion of soil and paint chips should be strictly discouraged or prevented. Prior to commencing renovation in homes built before 1978, the surfaces to be disturbed should be tested for the presence of lead-based

paint. If lead-based paint is found above the regulatory limit, contact the National Lead Information Center at 1-800-424-LEAD for guidance on how to proceed. Additional information on evaluation and control of lead-based paint in homes can be found in EPA publications at the following website:

<http://www.epa.gov/lead/leadpbed.htm>

In spite of lead bans and behavior precautions, lead poisoning remains a significant threat to human health — especially for children. Although the symptoms of moderate exposure may be subtle, the damage can be irreversible. Local health agencies can provide useful information on the need for blood lead testing. Should unsafe lead levels be discovered, medical treatment should be sought at once and the sources of exposure must be identified and dealt with carefully.

EPA's National Risk Management Research Laboratory, in cooperation with many other scientists and engineers, is working to better understand the scientific issues surrounding exposure to lead in soil. By continuing to develop and refine assessment and remediation tools, EPA will be better poised to offer real solutions — *like the patented hydroxyapatite treatment process* — to high priority risks faced by our society. Through increased awareness of the dangers associated with lead exposure, and continued innovative risk management research, a safer environment can be provided.

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For additional information about U.S. EPA's risk management research, visit the following internet web site:

<http://www.epa.gov/ORD/NRMRL>

To learn more about lead bioavailability and related topics, visit the following U.S. EPA Technical Workgroup for Lead internet web site:
<http://www.epa.gov/superfund/programs/lead/>

For more information on the risks and control of lead hazards, visit the U.S. Dept. of Housing and Urban Development's Office of Lead Hazard Control internet web site:
<http://www.hud.gov/offices/lead/index.cfm>

This publication was written and produced by Patrick Burke and Jim Ryan of USEPA's National Risk Management Research Laboratory (NRMRL) within the Office of Research and Development. Comments were provided by Rufus Chaney, U.S. Department of Agriculture's Agricultural Research Services, and Bill Berti, DuPont Company and IINERT RTDF.

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